



# **Sensor Design and Operation for Extreme Environments**

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# What are extreme environments?

- Very low and very high temperatures
- Thermal Cycling between temperatures
- High ionizing radiation
- High magnetic fields
- High vibration (launch conditions)

Notes:

- 1) “Extreme Environment” is not well defined.
- 2) The requirements for sensors/electronics operating in the “extreme environment” depend entirely upon the application.

# What Quantities Need To Be Measured?

- Temperature
- Pressure
- Physical Position
- Flow
- Magnetic Field
- Stress/Strain
- Liquid level
- Intensity
- Radiation

# Problem Broken Into Two Realms

- Sensors whose output/response change with respect only to the desired stimulus.
- Electronic components whose characteristics should not change with respect to any external conditions.

# Focus on temperature sensors for three reasons:

- 1) Temperature is the most often measured physical quantity.
- 2) Temperature sensors respond not only to changes in temperature (as desired), but also to secondary effects caused by extreme temperatures (as undesired).
- 3) By their nature, temperature sensors are subjected to at least one extreme environment.



# Temperature Sensors

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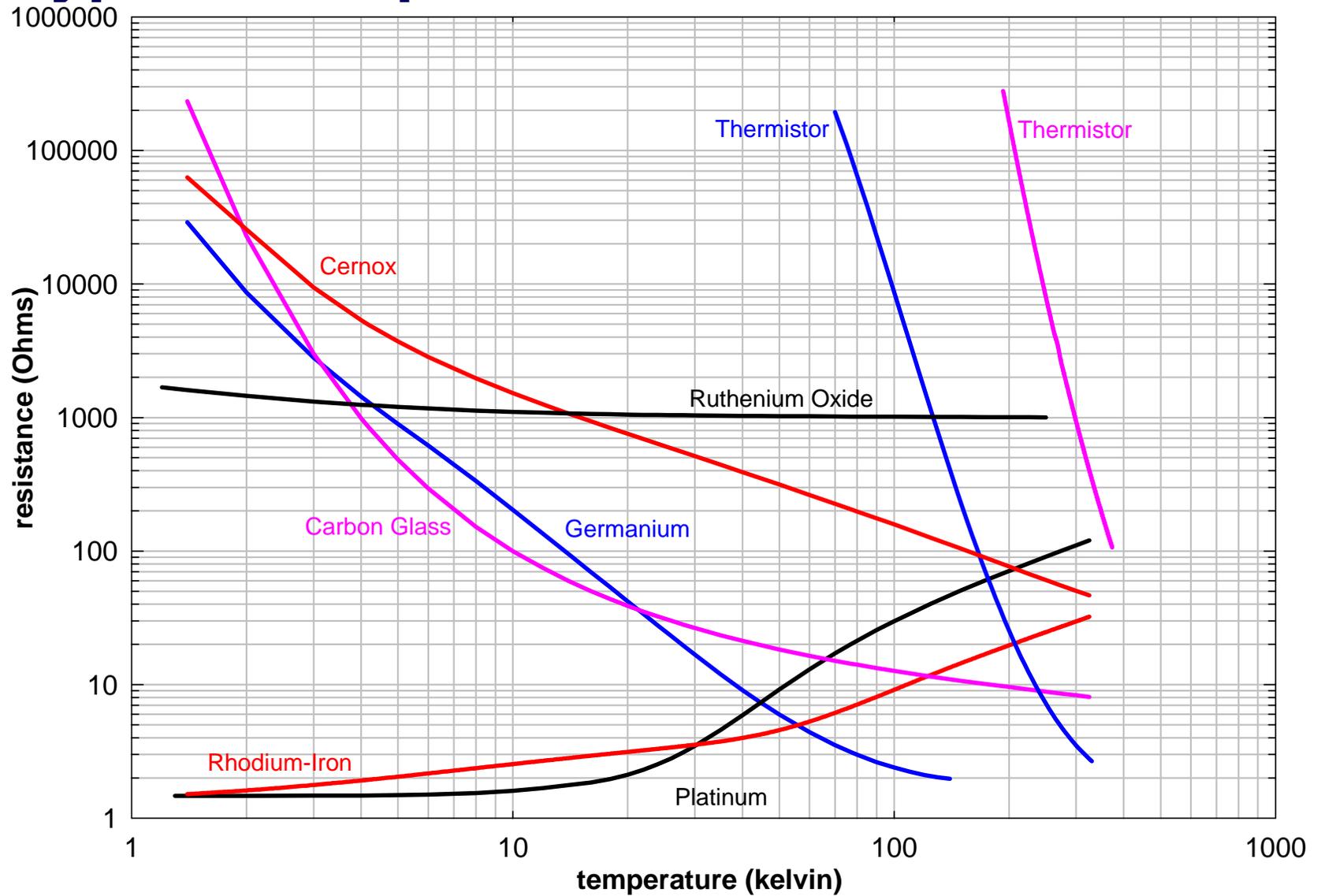
# What do you measure to get temperature?

- Practical
  - Resistance
  - Voltage
  - Forward Voltage of a p-n junction
  - Capacitance
- Impractical
  - Gas vapor pressure
  - Blackbody radiation
  - Fixed points
  - Noise
  - Radiation pattern

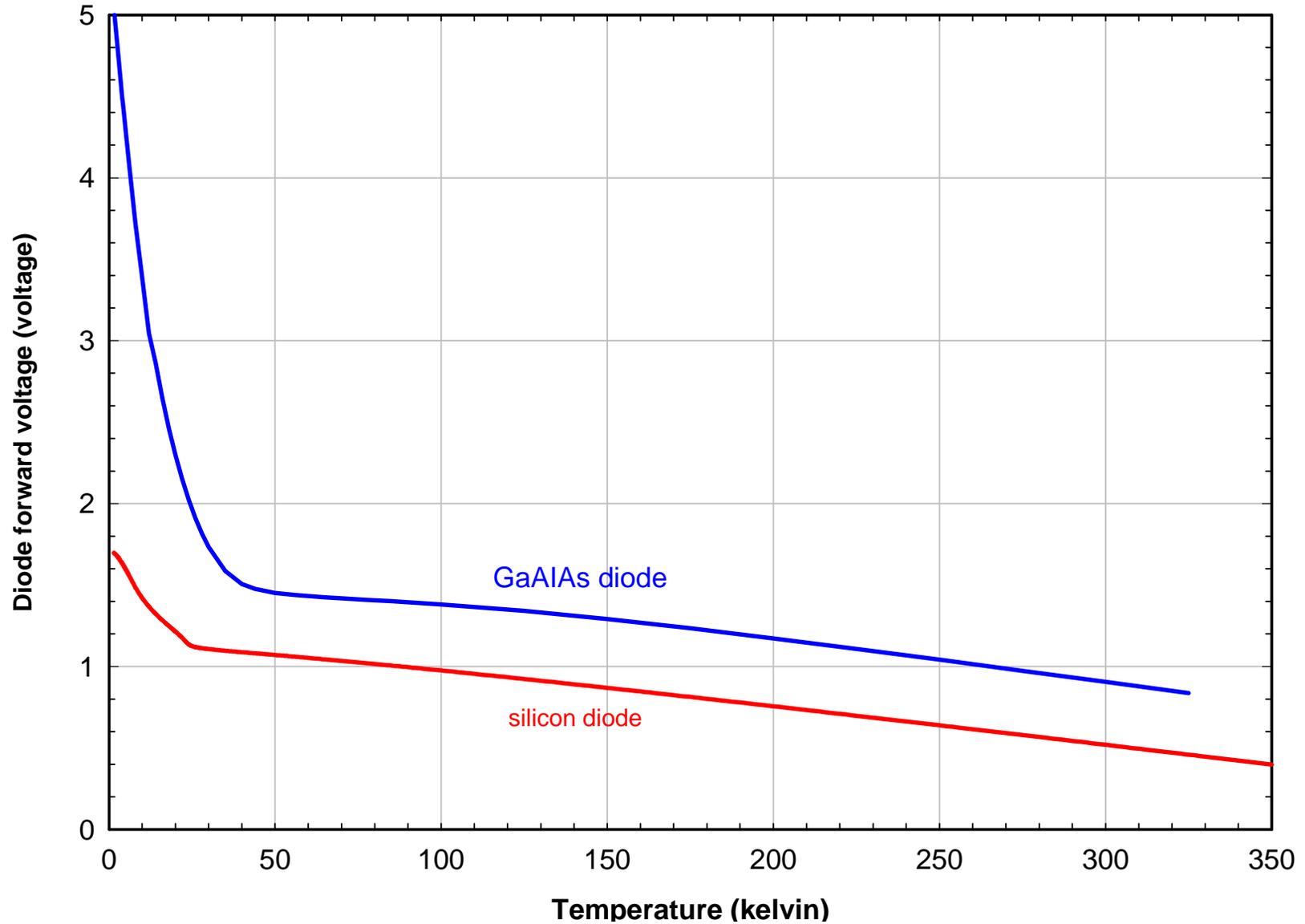
# Types of Temperature Sensors

- Positive Temperature Coefficient (Metallic)
  - Platinum, Rhodium-Iron, Platinum-Cobalt RTDs
- Negative Temperature Coefficient (Nonmetallic)
  - Germanium, Cernox, Carbon Glass, Ruthenium Oxide, Carbon, Thermistors RTDs
  - Silicon and Gallium-Arsenide diodes
- Other
  - Thermocouples (PTC)
  - Capacitors (non-monotonic)

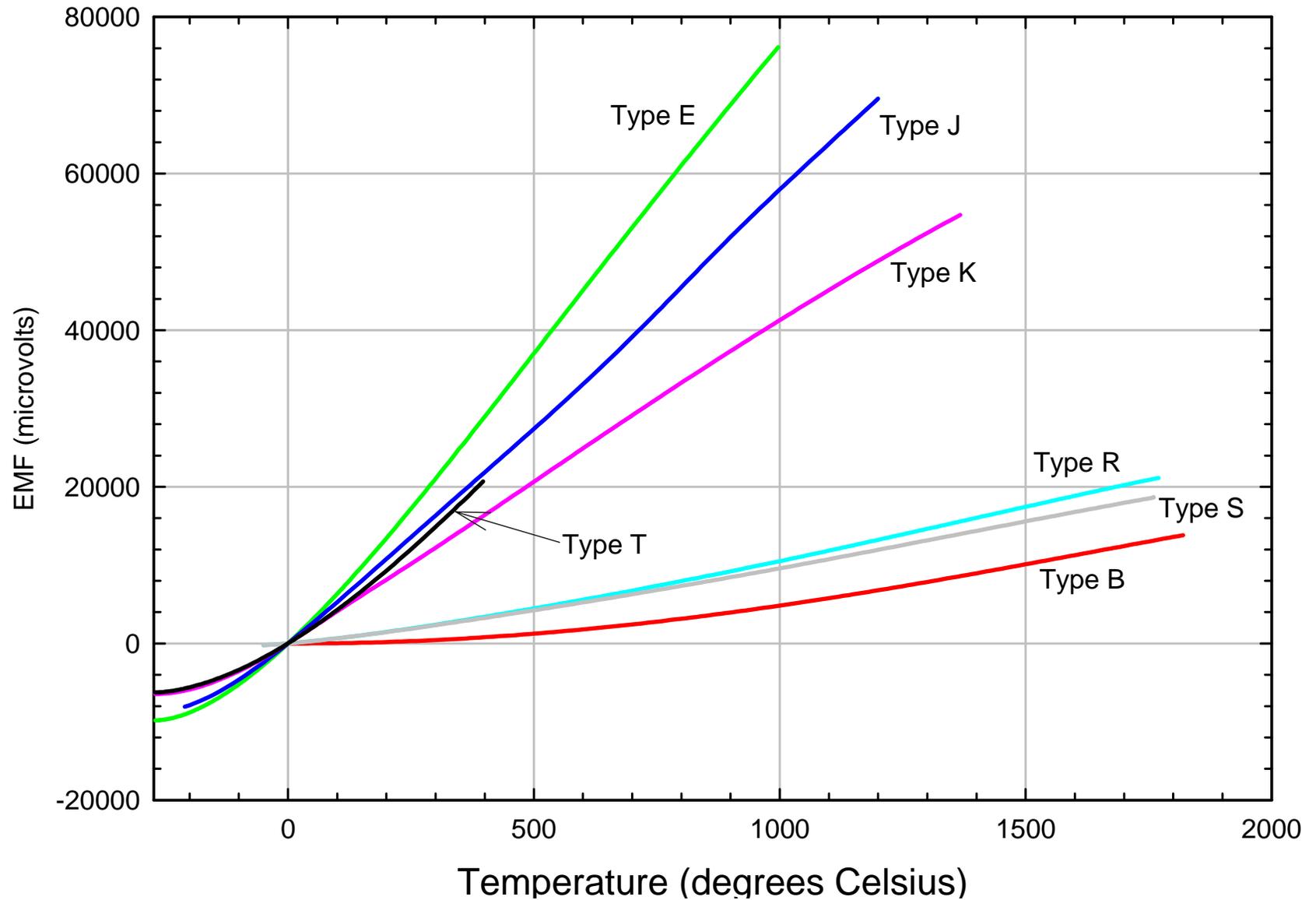
# Typical Temperature Sensor R-T curves



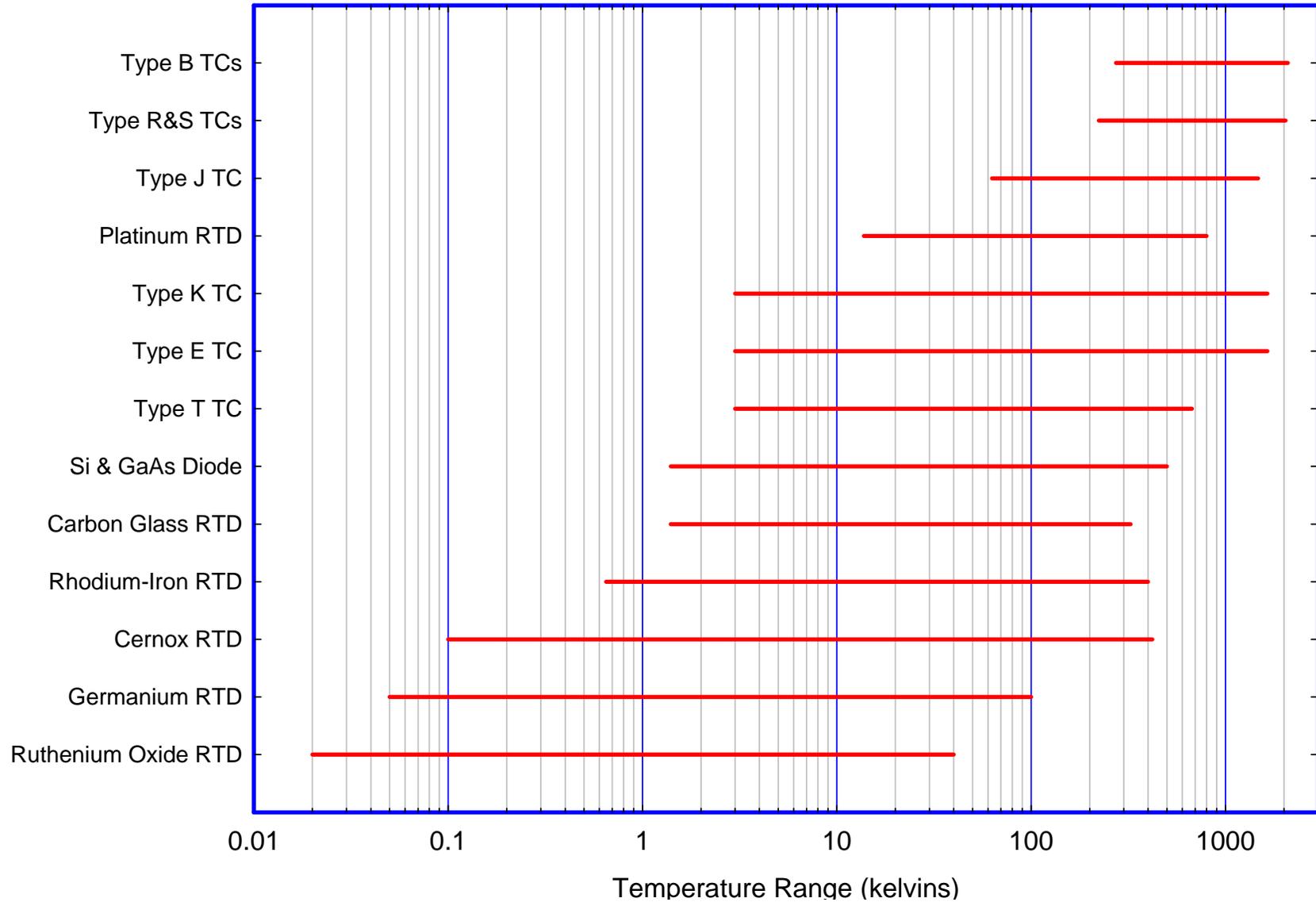
# Typical Temperature Sensor V-T curves



# Typical Thermocouple V-T curves



# Temperature Sensor Ranges





# Installation and Operation

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## Installation

- Low thermal conductivity wire - minimize heat load from higher temperature surroundings.
- Heat sink leads as appropriate – minimize heat load from higher temperature surroundings.
- Low Thermal EMF materials (refer to Keithley handbook on Low Level Measurements)
- Twisted pairs for wiring - (reduces AC noise)
- Four-lead measurements (eliminates lead resistance errors).
- Use expansion-coefficient compatible materials for rigid mounting of sensor

# Operation

- Current reversal – eliminates thermal EMFs.
- Power Level – keep low to avoid self-heating and to avoid heating the system to which it is attached.



# Temperature Sensor Construction

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# Temperature Sensor Fabrication

- Sensor material must be stable and compatible with the temperature range.
- Sensor mounting/packaging must be compatible with the temperature range.
- Expansion/contraction coefficients must be compatible for materials in contact with one another. (Typically within a factor of 3.)

Temperature induced stress/strain is a major problem for temperature sensors resulting in failure, shifting and/or erroneous readings.

# Material Temperature Ratings:

- Stycast 2850 / Cat 9: -40 to +130 °C
- Stycast 2850 / Cat 11: -55 to +155 °C
- Stycast 1266 / Cat A or Cat B: -65 to +105 °C
- Tra-Duct 2902 Silver Epoxy: -60 to +110 °C
- Formvar insulation: ? to +105 °C
- Teflon PFA insulation: -240 to +260 °C
- Polyimide insulation: -270 to +400 °C
- N-grease: -269 to +30 °C
- Dow Corning Vacuum grease: -40 to +204 °C

Many commonly used materials aren't rated for cryogenic use!

# Some Materials Used in Construction

- Packaging

Alumina, Sapphire, BeO, Copper, Silicon, Stainless Steel, Glass, Teflon, epoxy

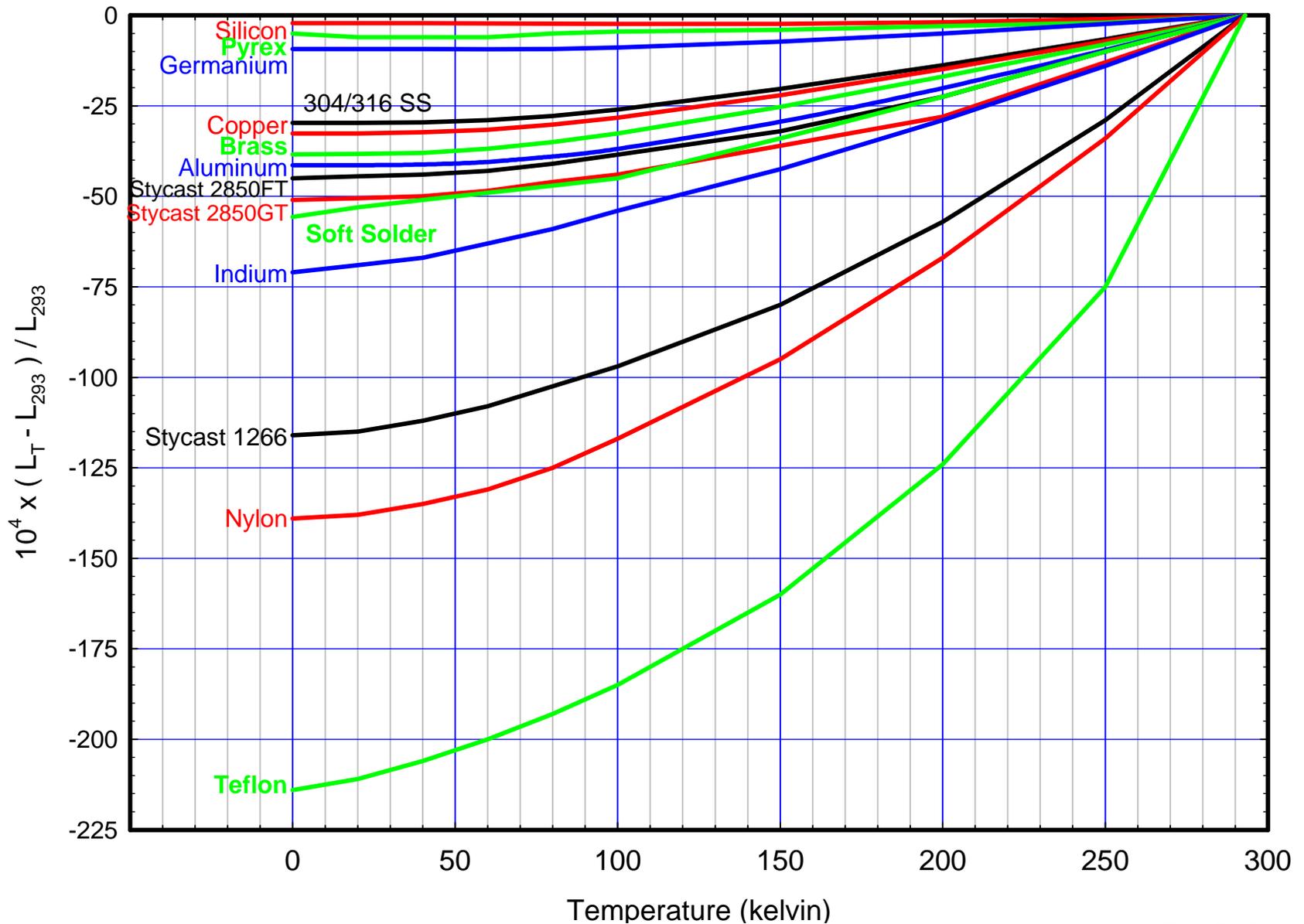
- Electrical Connections

Lead-Tin solder, Indium solder, Gold wire bonds, Gold-silicon eutectic, Silver epoxy, Spot welds

- Wire

Copper, Gold, Stainless Steel, Manganin, Phosphor Bronze, Constantan, Aluminum, Evan-ohm, Platinum (Polyimide, Formvar, Teflon, and Fiberglass insulation)

# Thermal Expansion Of Select Materials

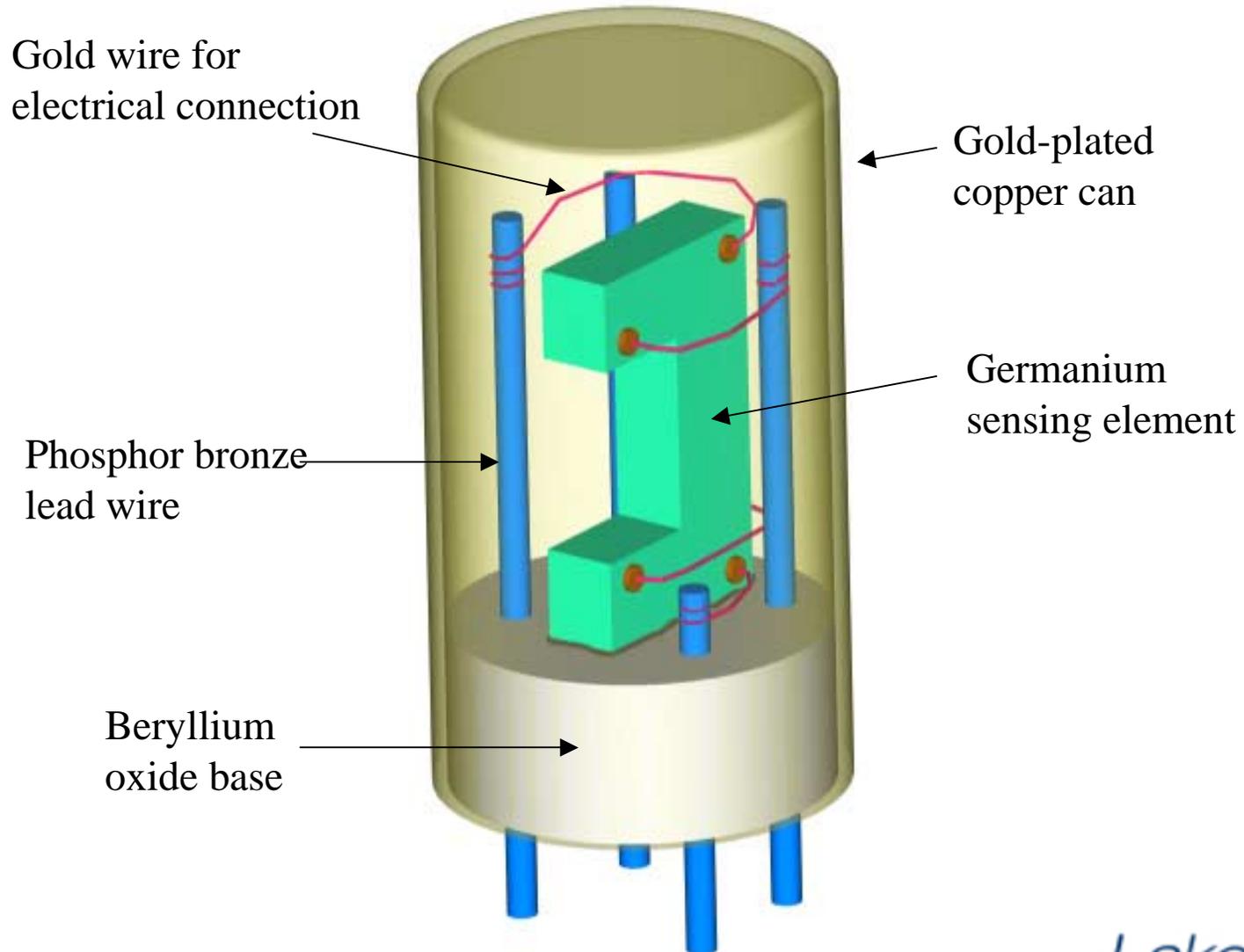


# Sensor Design Consideration

- Contacting methods must be compatible electrically and chemically.
- Packaging methods must be compatible chemically.
- Sensor and Construction materials must be compatible mechanically.

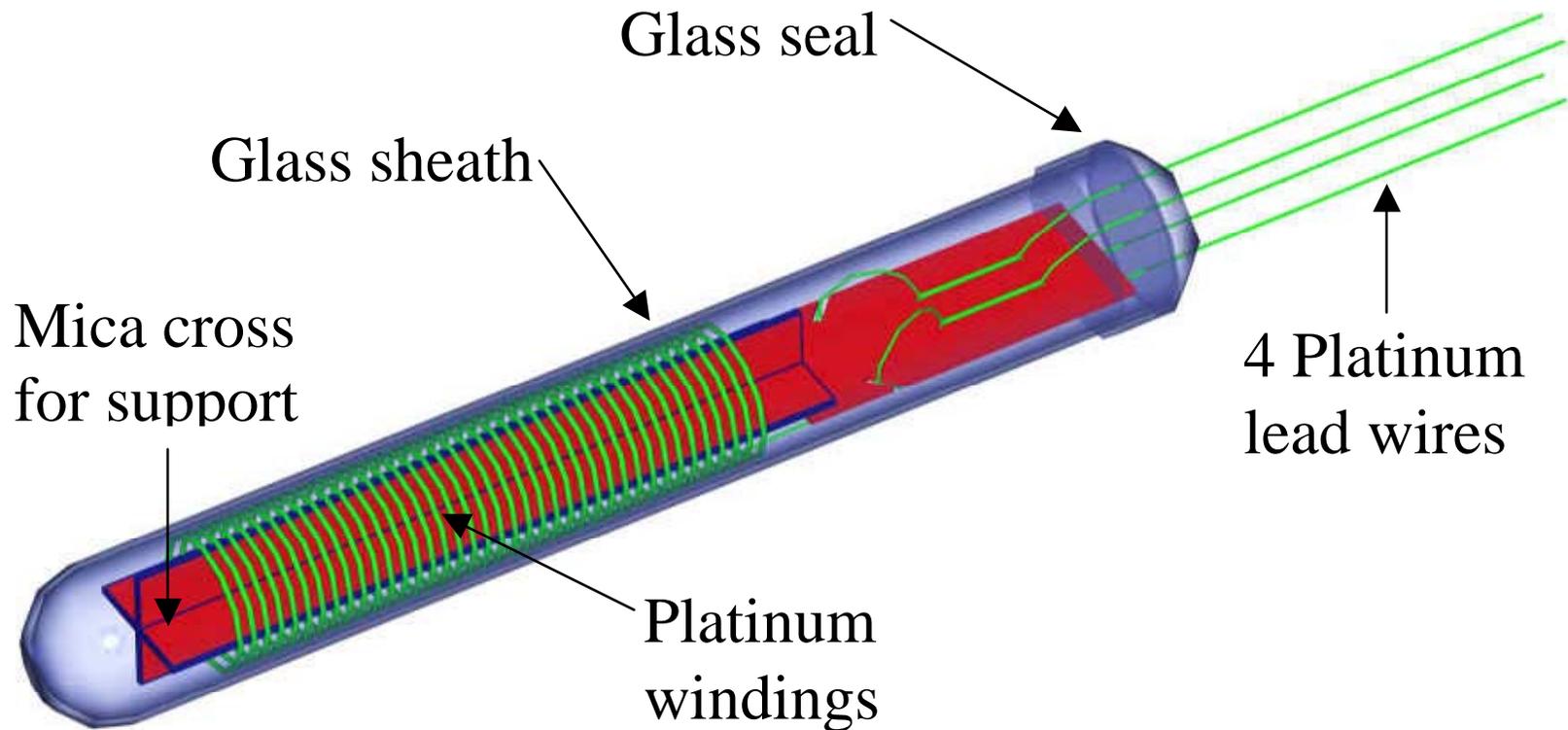
# Temperature Sensor Design Example 1

## Germanium RTDs



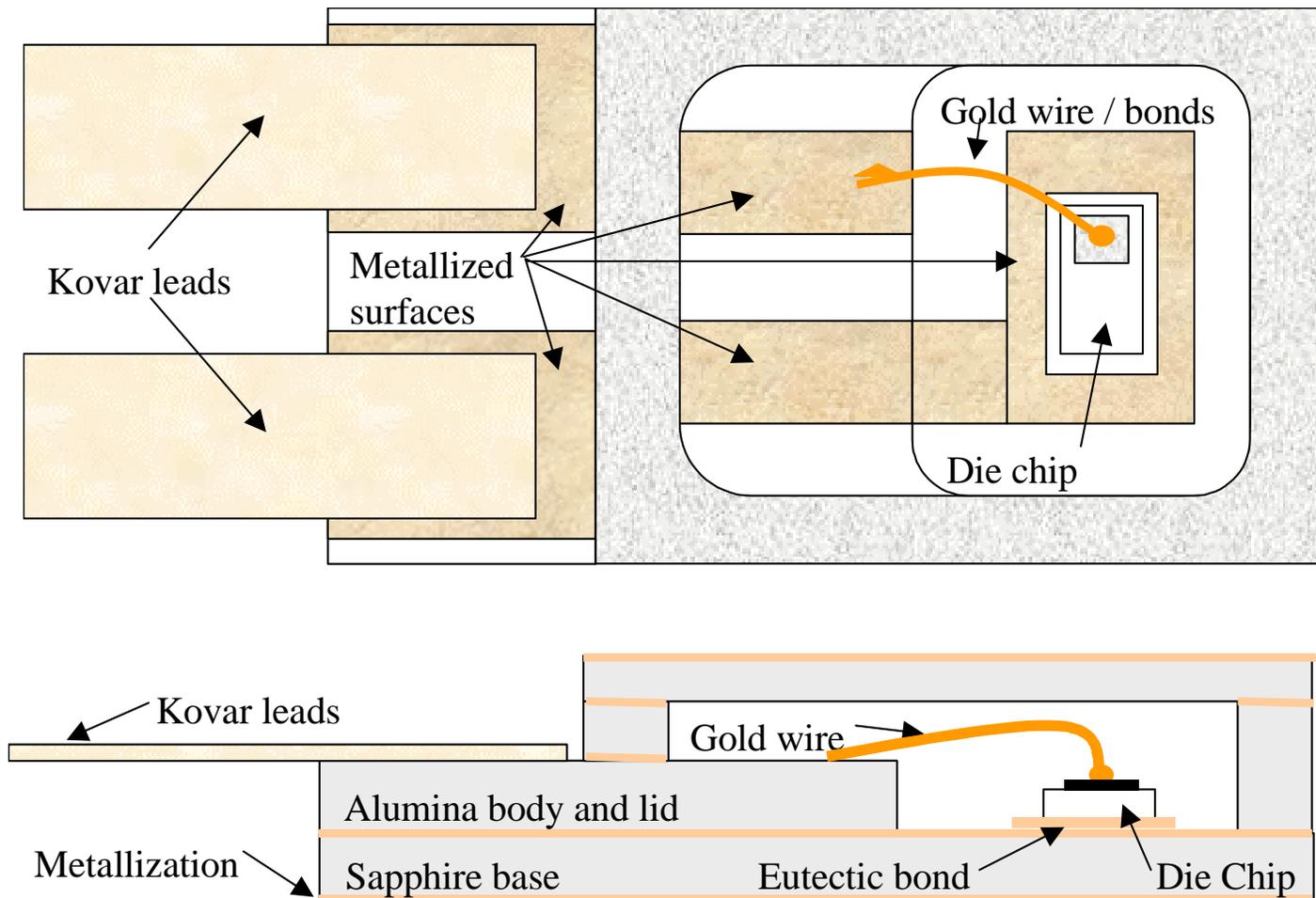
# Temperature Sensor Design Example 1

## Platinum Standards Grade RTDs



# Temperature Sensor Design Example 3

## Diode thermometer



# How much change is too much?

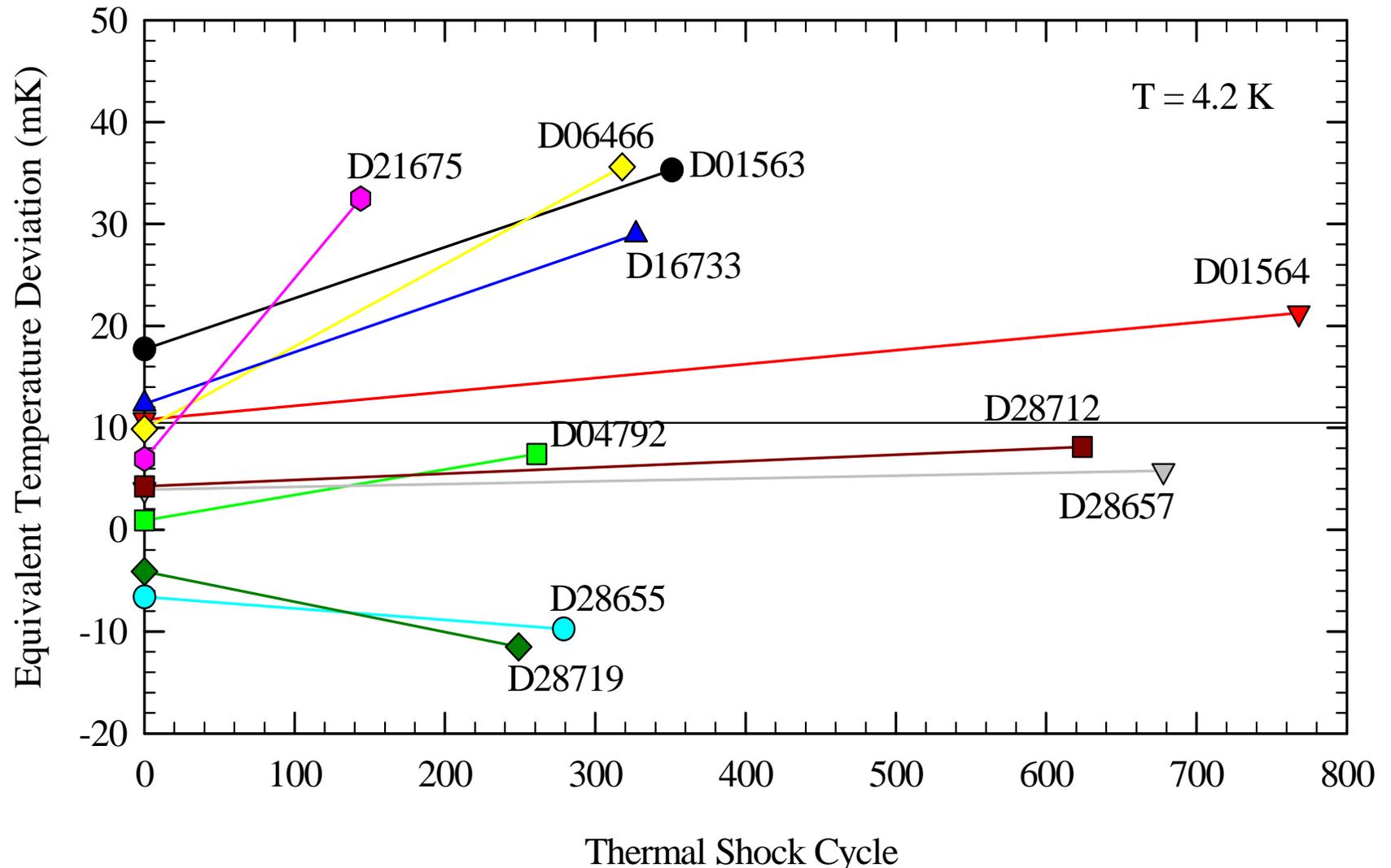
- Consider an induced 1% change in resistance thermometer:
  - For a platinum RTD at 300 K, the equivalent temperature offset is 2.75 K.
  - For a Cernox RTD at 300 K, the equivalent temperature offset is 4 K
- Consider an induced 1% change in forward voltage drop for a diode thermometer
  - For a silicon diode thermometer at 300 K, the equivalent temperature offset is 2.2 K



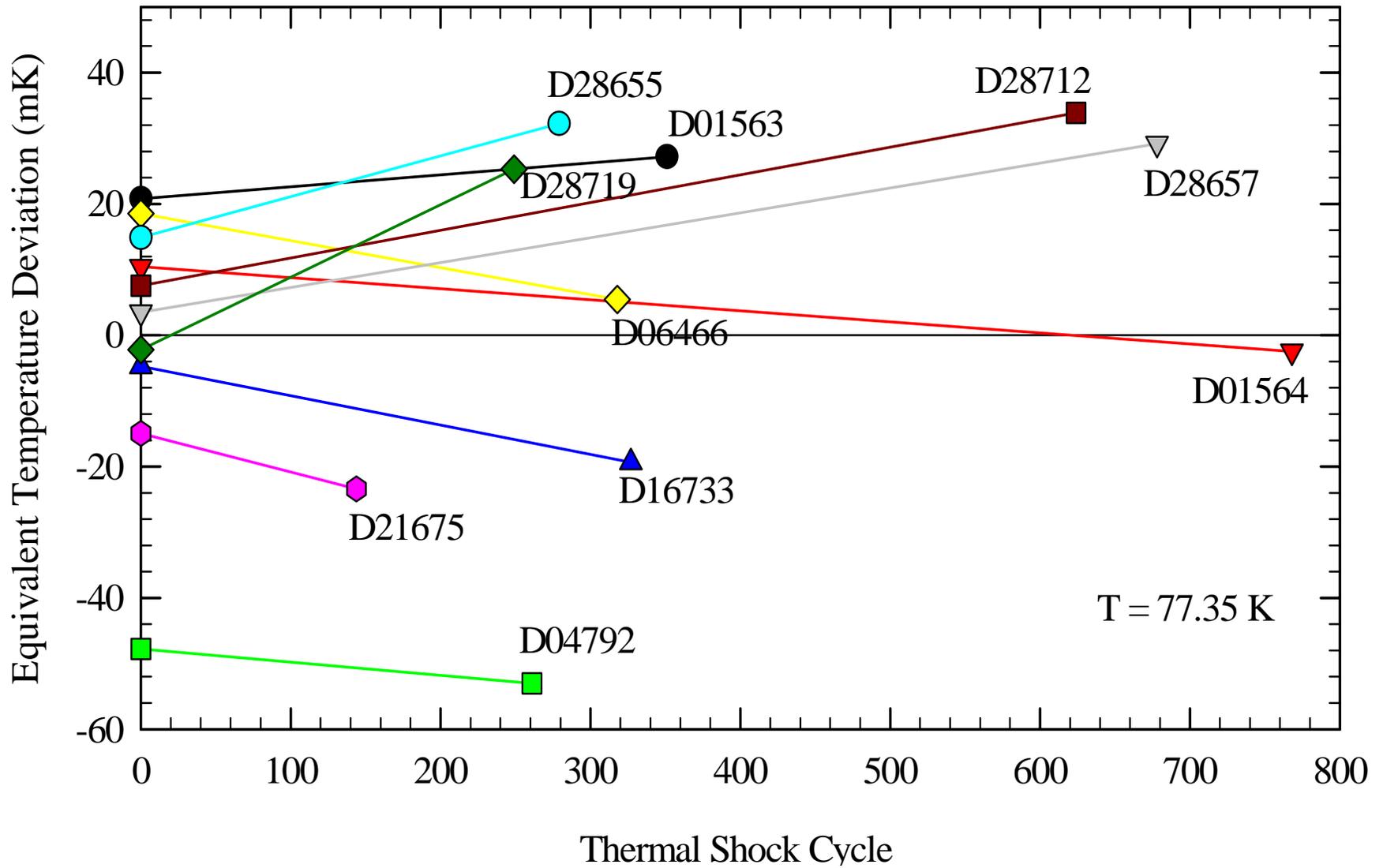
# Effects of Thermal Cycling

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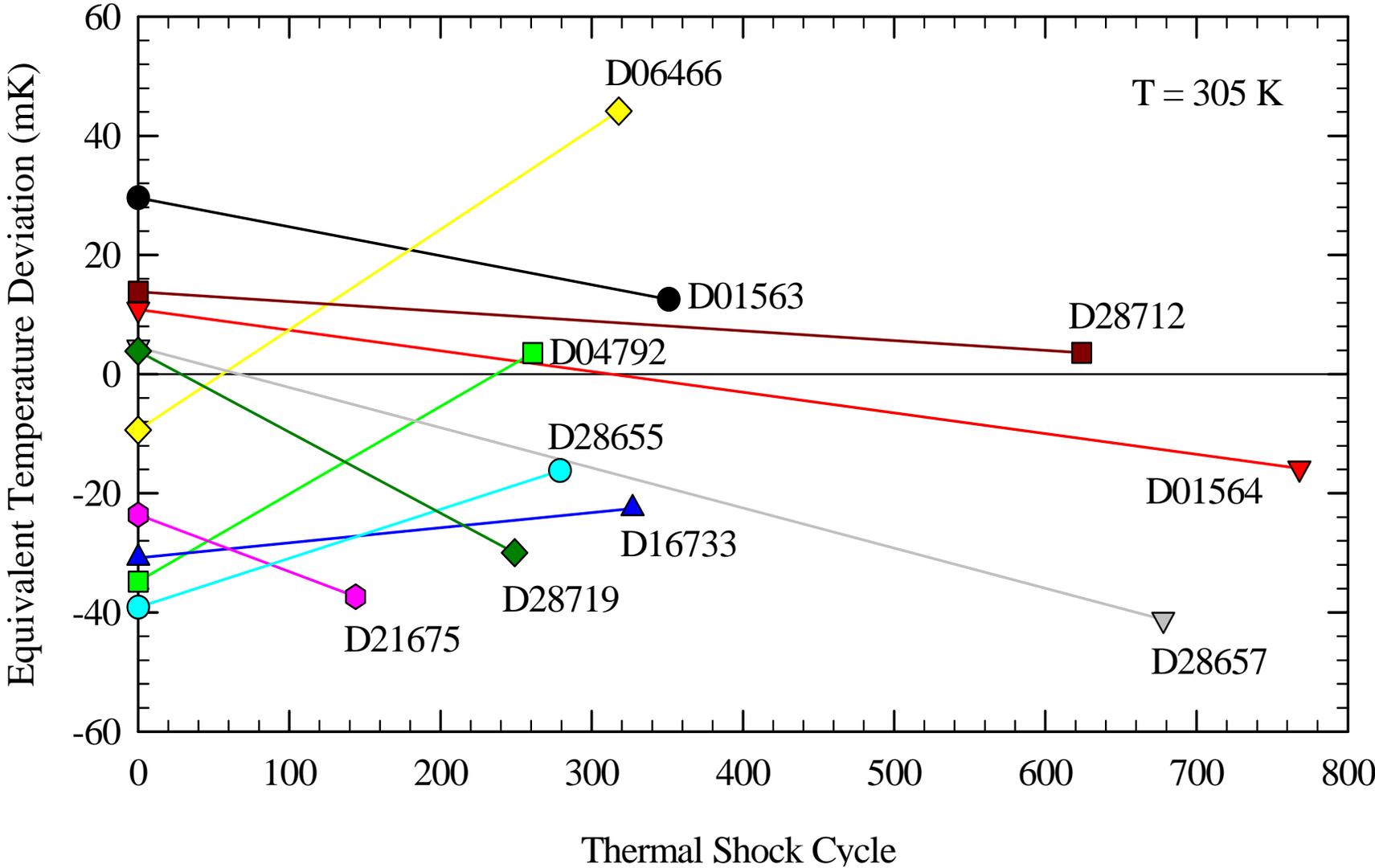
# Effects of Thermal Cycling – Silicon Diode



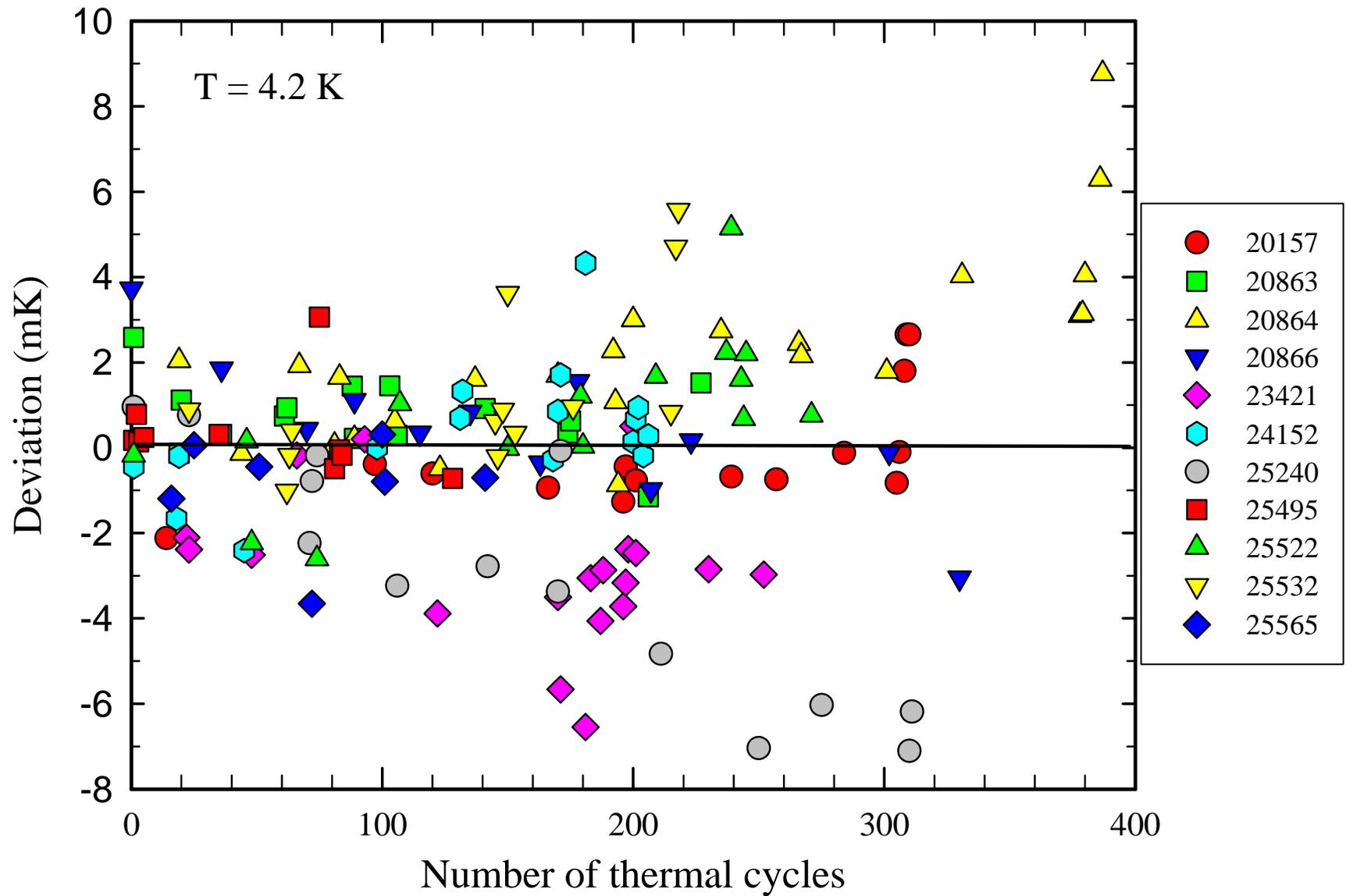
# Effects of Thermal Cycling – Silicon Diode



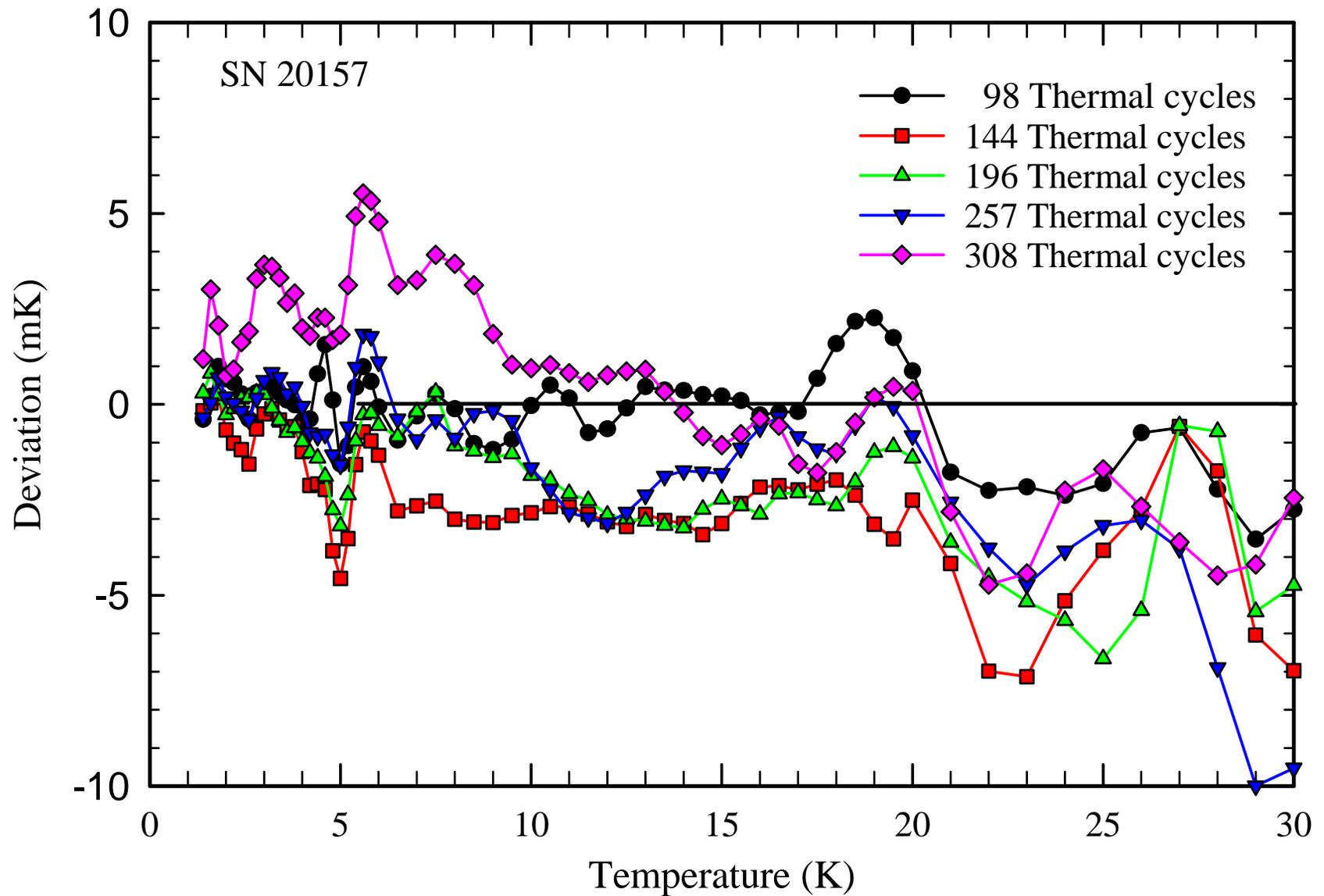
# Effects of Thermal Cycling – Silicon Diode



# Effects of Thermal Cycling – Germanium RTD



# Effects of Thermal Cycling – Germanium RTD

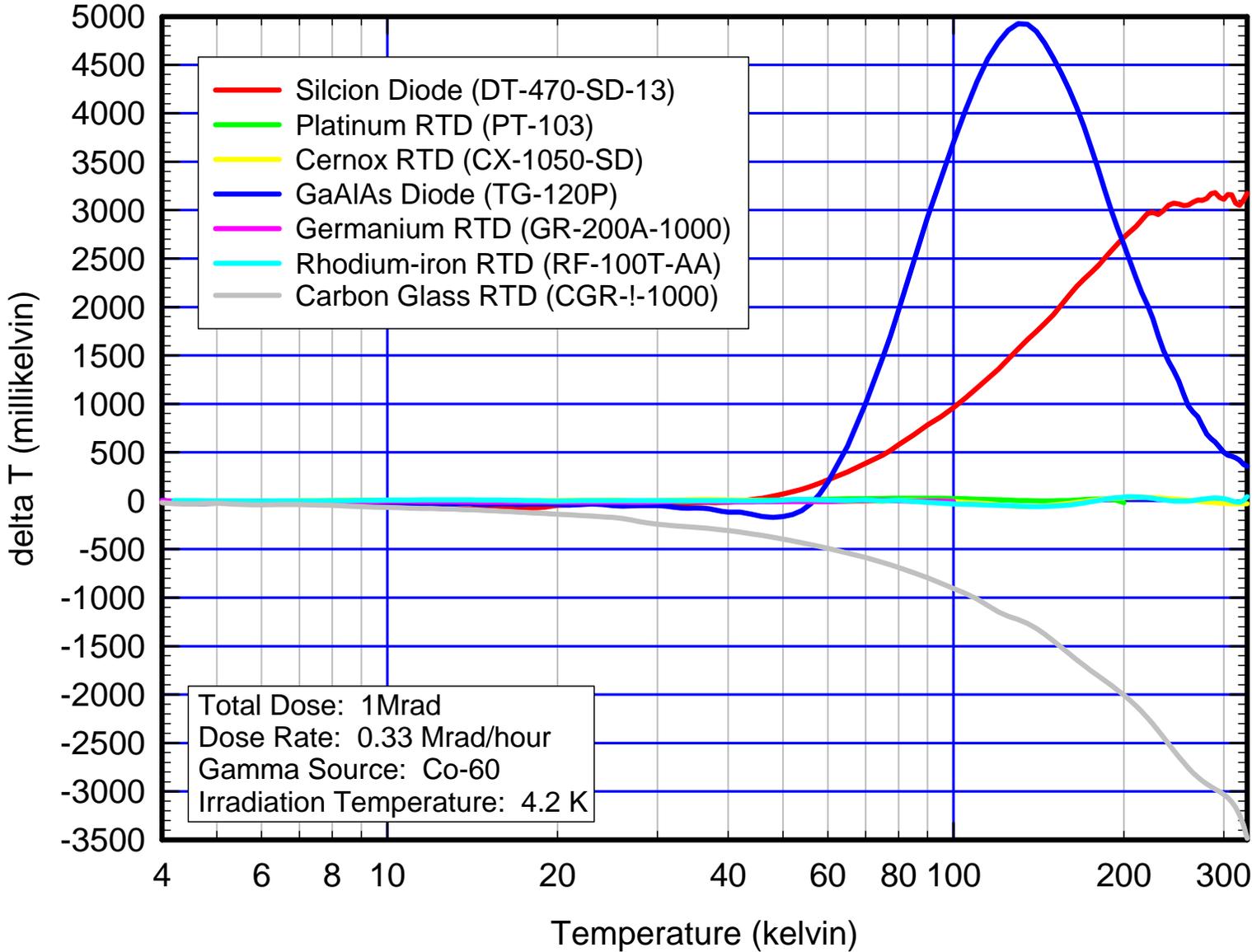




# Effects of Radiation

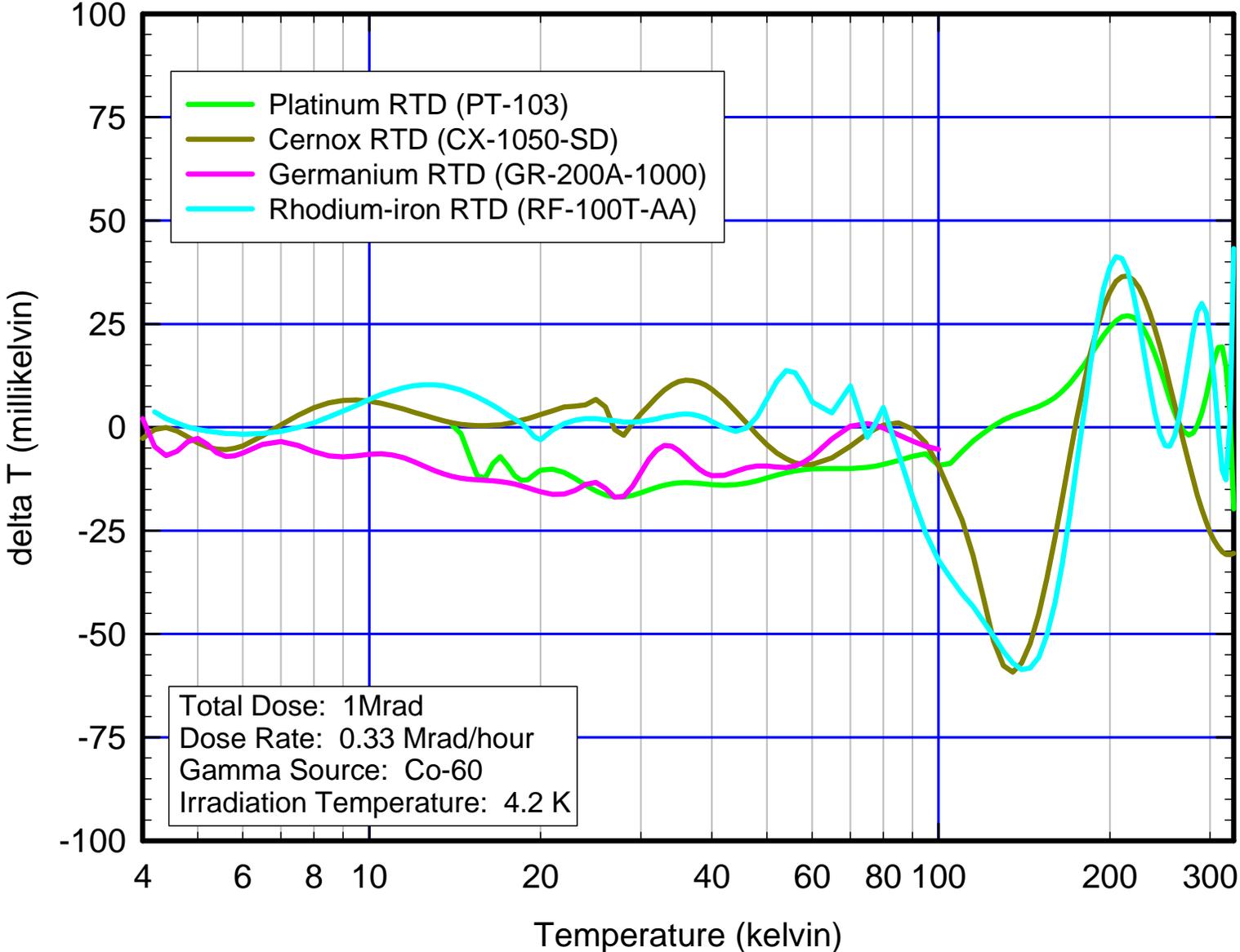
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# Effects of 1 Mrad Gamma Radiation – 1



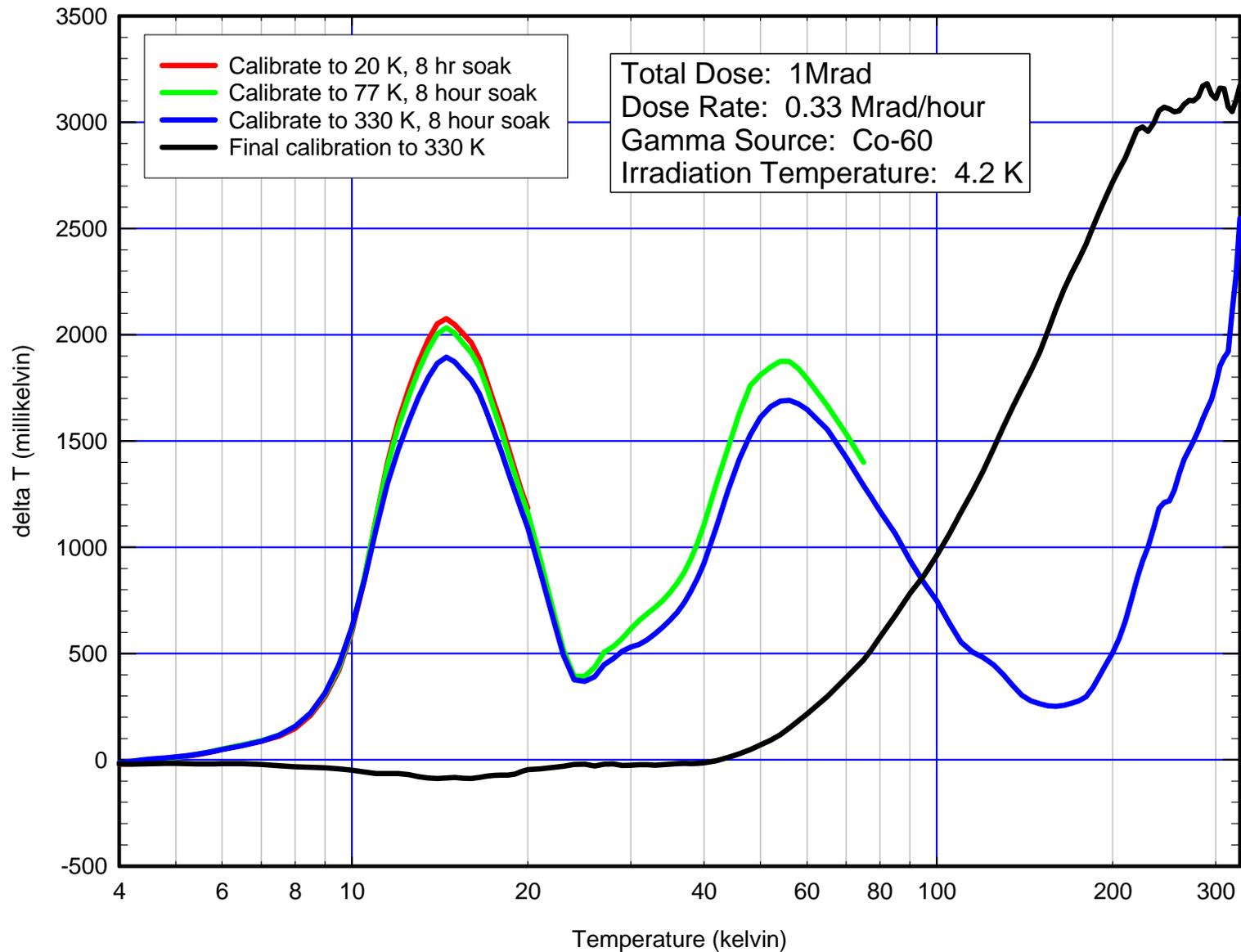
Total Dose: 1Mrad  
Dose Rate: 0.33 Mrad/hour  
Gamma Source: Co-60  
Irradiation Temperature: 4.2 K

# Effects of 1 Mrad Gamma Radiation – 2

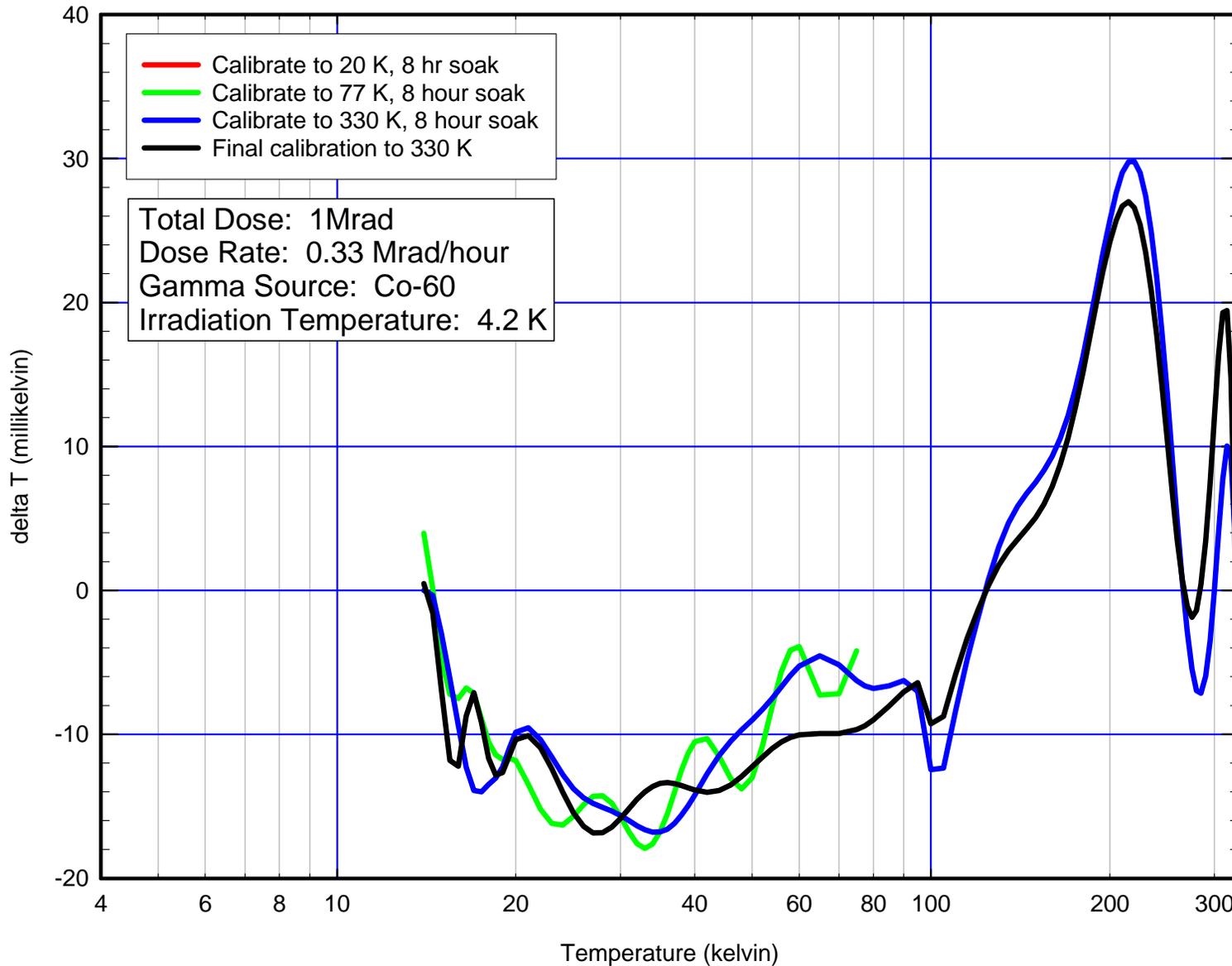


Total Dose: 1Mrad  
Dose Rate: 0.33 Mrad/hour  
Gamma Source: Co-60  
Irradiation Temperature: 4.2 K

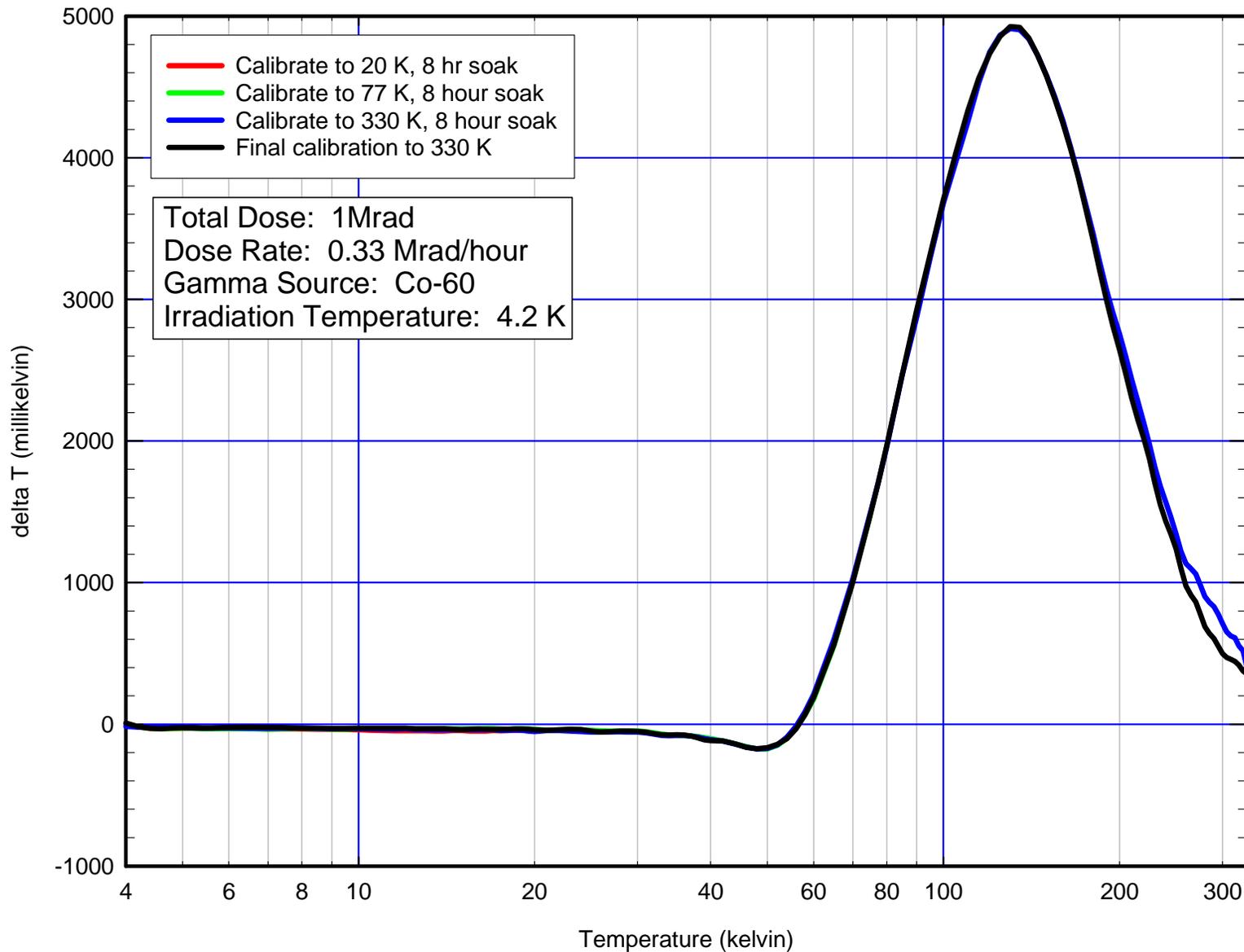
# Thermal Annealing – Silicon Diode



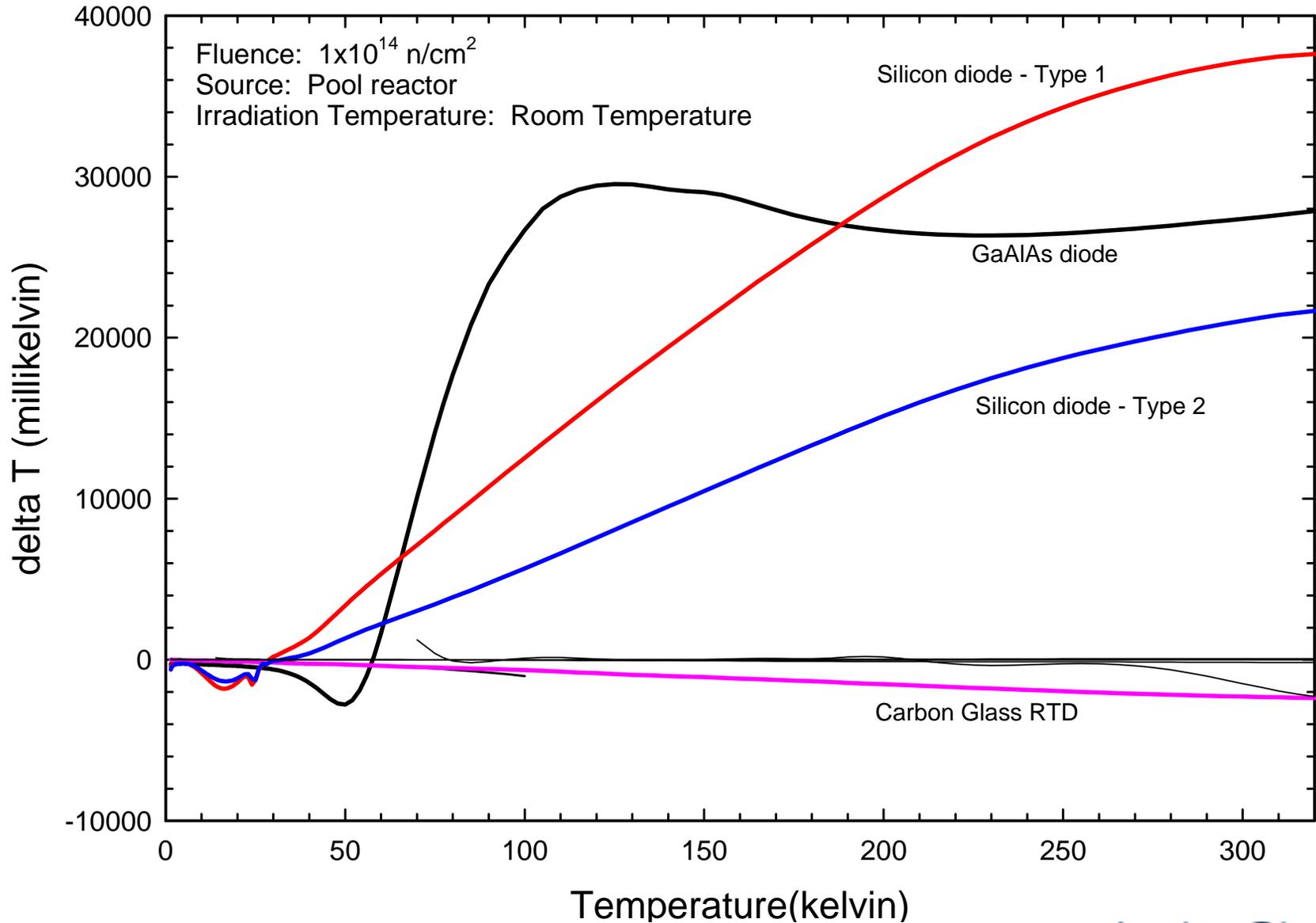
# Thermal Annealing – Platinum RTD



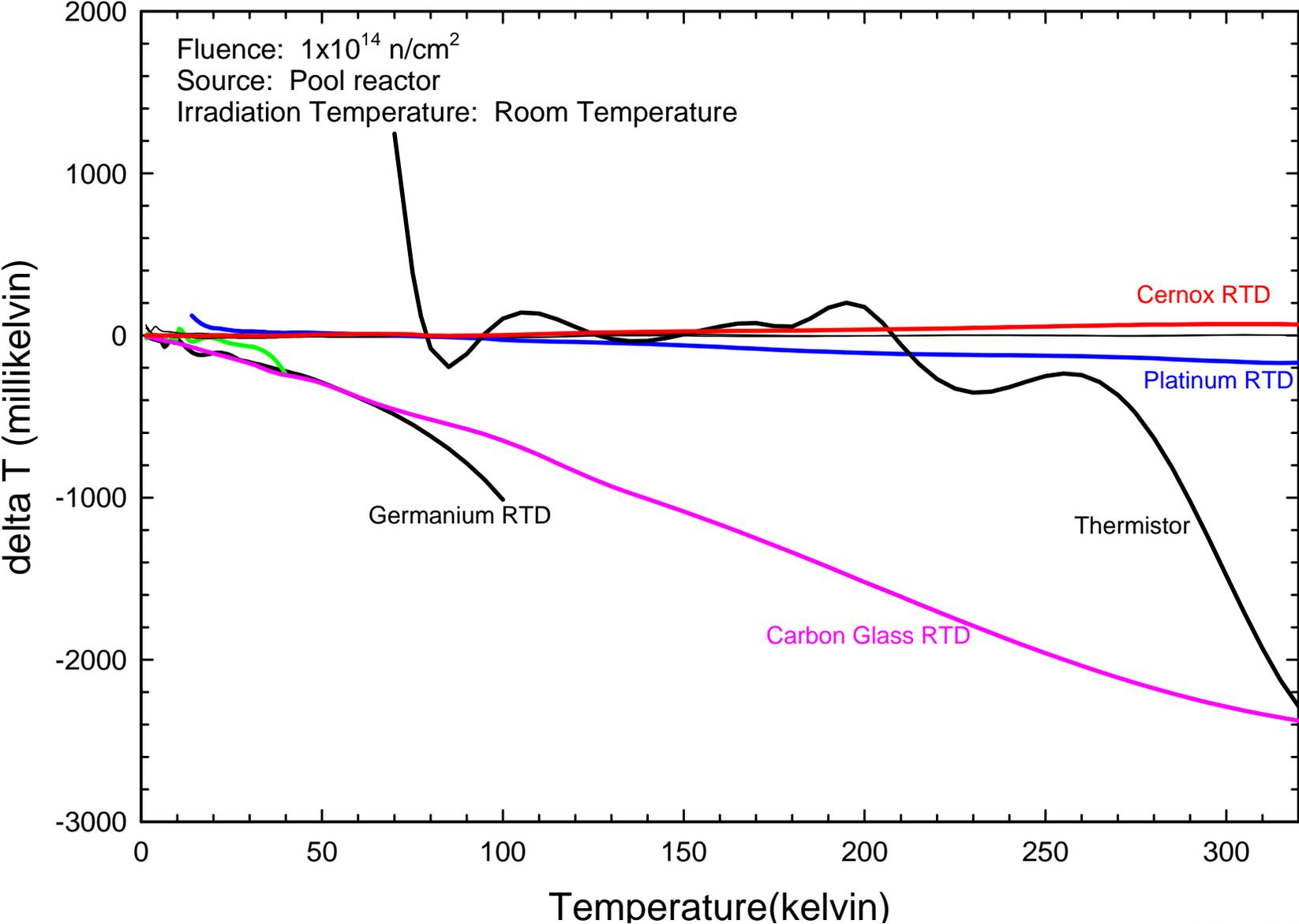
# Thermal Annealing – GaAlAs Diode



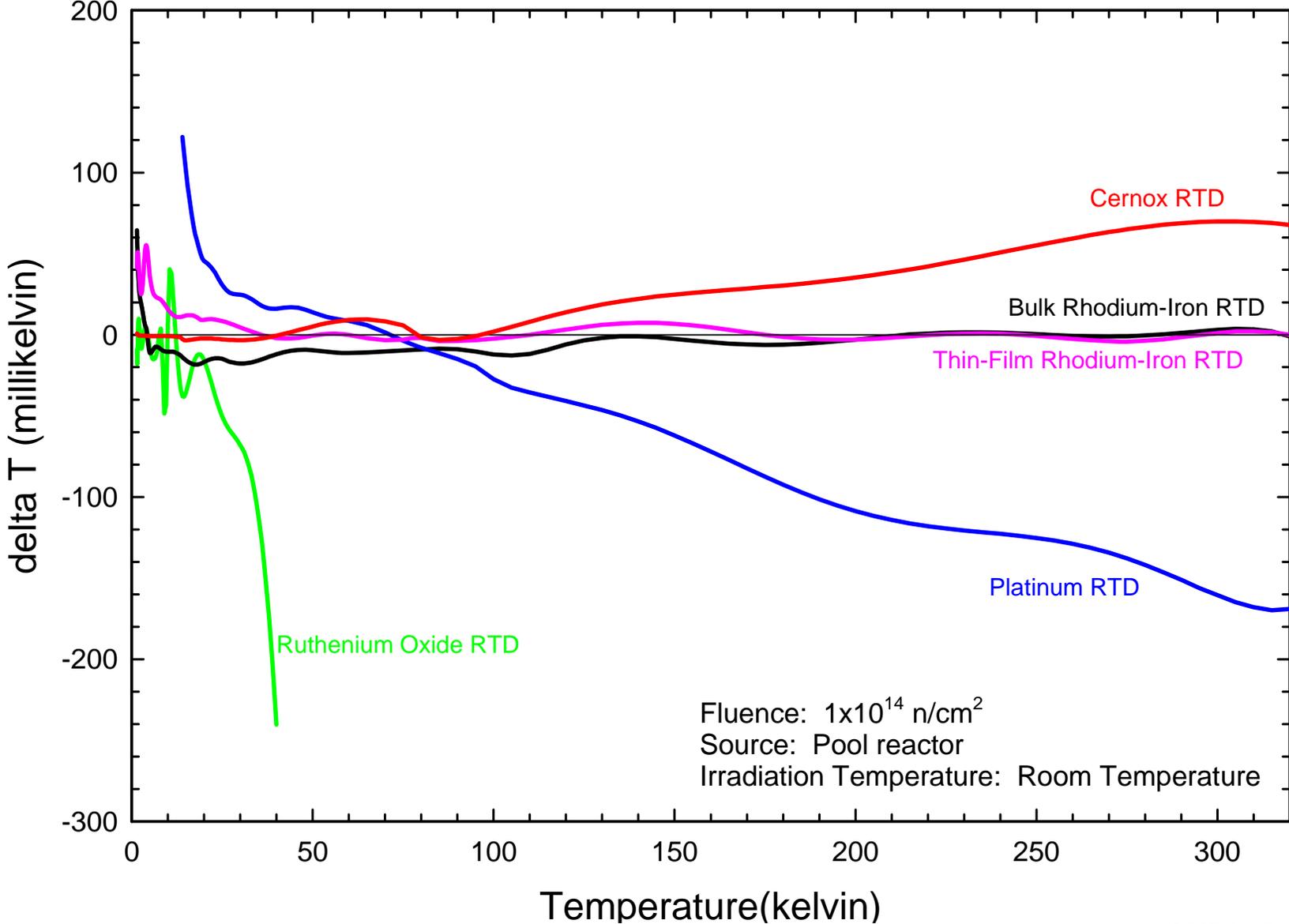
# Effects of $1 \times 10^{14}$ neutrons/cm<sup>2</sup> - close



# Effects of $1 \times 10^{14}$ neutrons/cm<sup>2</sup> – closer



# Effects of $1 \times 10^{14}$ neutrons/cm<sup>2</sup> – closest



Fluence:  $1 \times 10^{14}$  n/cm<sup>2</sup>  
Source: Pool reactor  
Irradiation Temperature: Room Temperature

# Conclusions

- Not likely to get everything you want in a sensor. Compromise to get the features most important for the application.
- Materials used in sensor fabrication must be compatible both electrically, chemically and mechanically.
- Testing of a sensor must be accomplished in a manner simulating the final application. Results based on room temperature testing may not give a complete picture.